CO_2 Sequestration, Fault Stability and Seal Integrity at Teapot Dome, Wyoming

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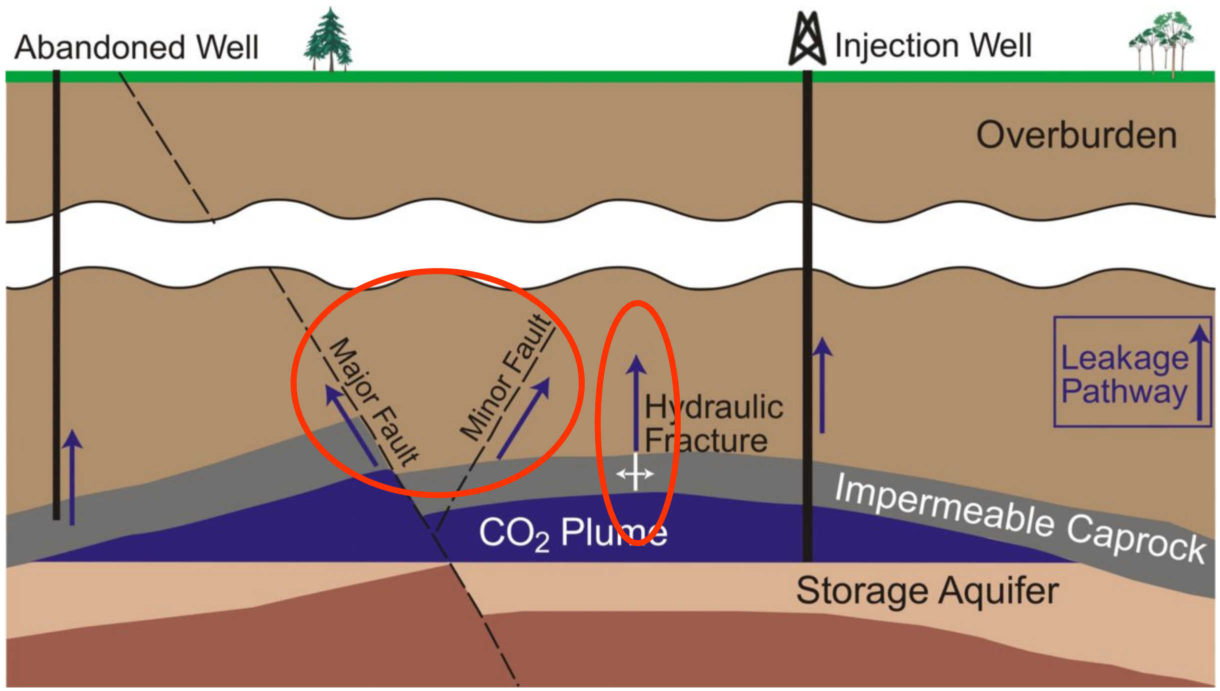
Motivation

Understanding leakage risk and ability to predict it are key steps for CO_2 sequestration

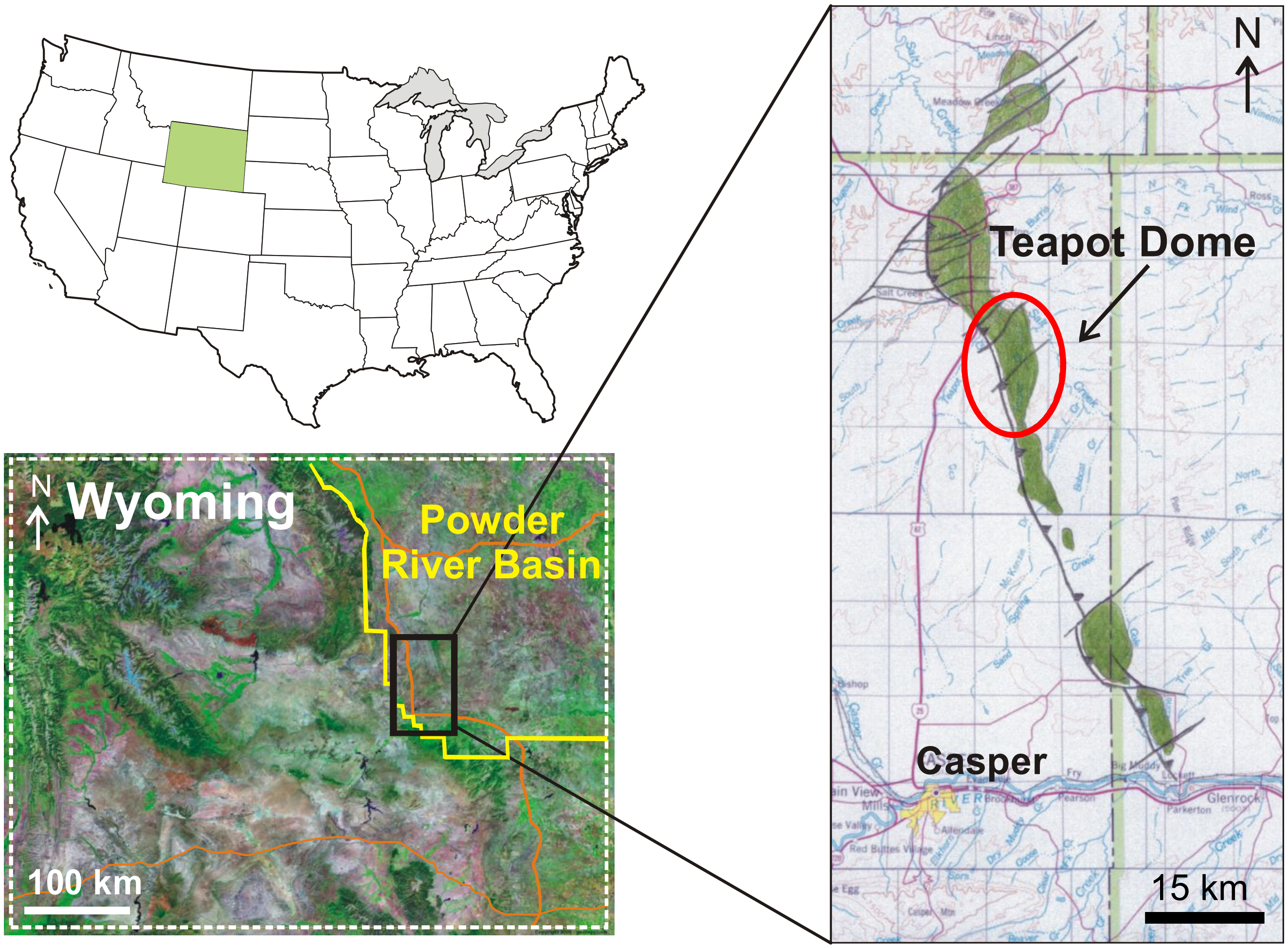


(Courtesy of A. Lucier)

Leakage in Oil & Gas Fields

Case Study Location – CO_2 - EOR Pilot

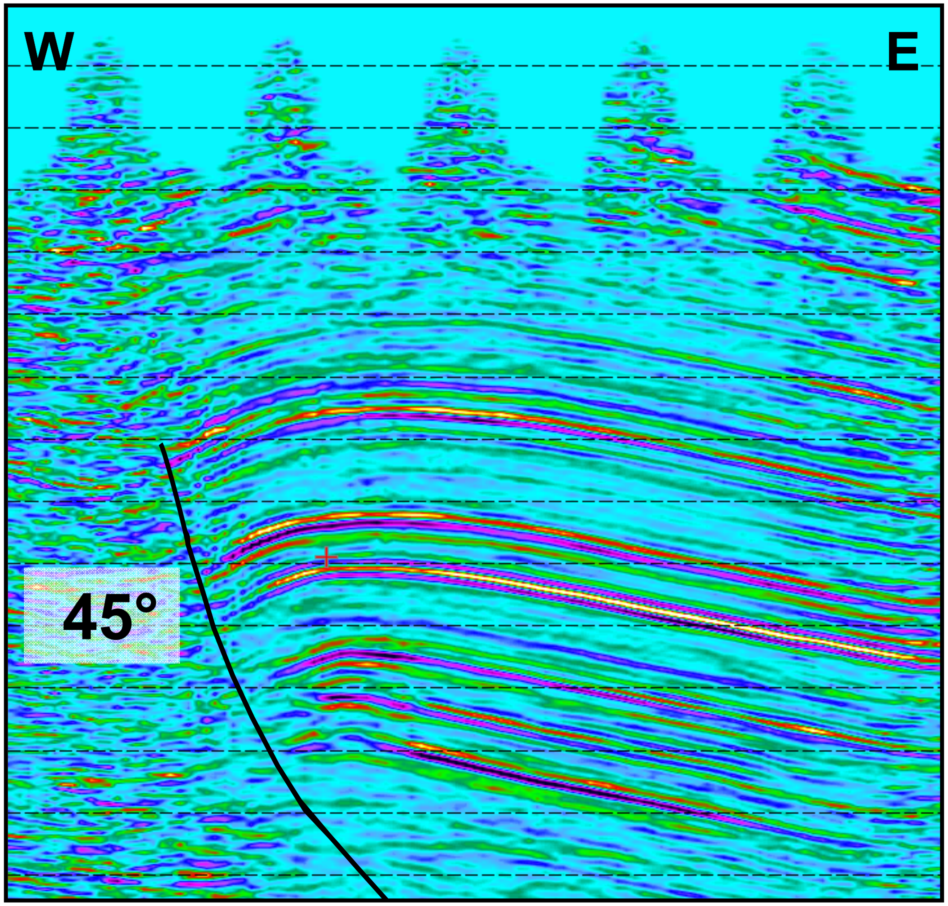
Teapot Dome Oilfield, WY



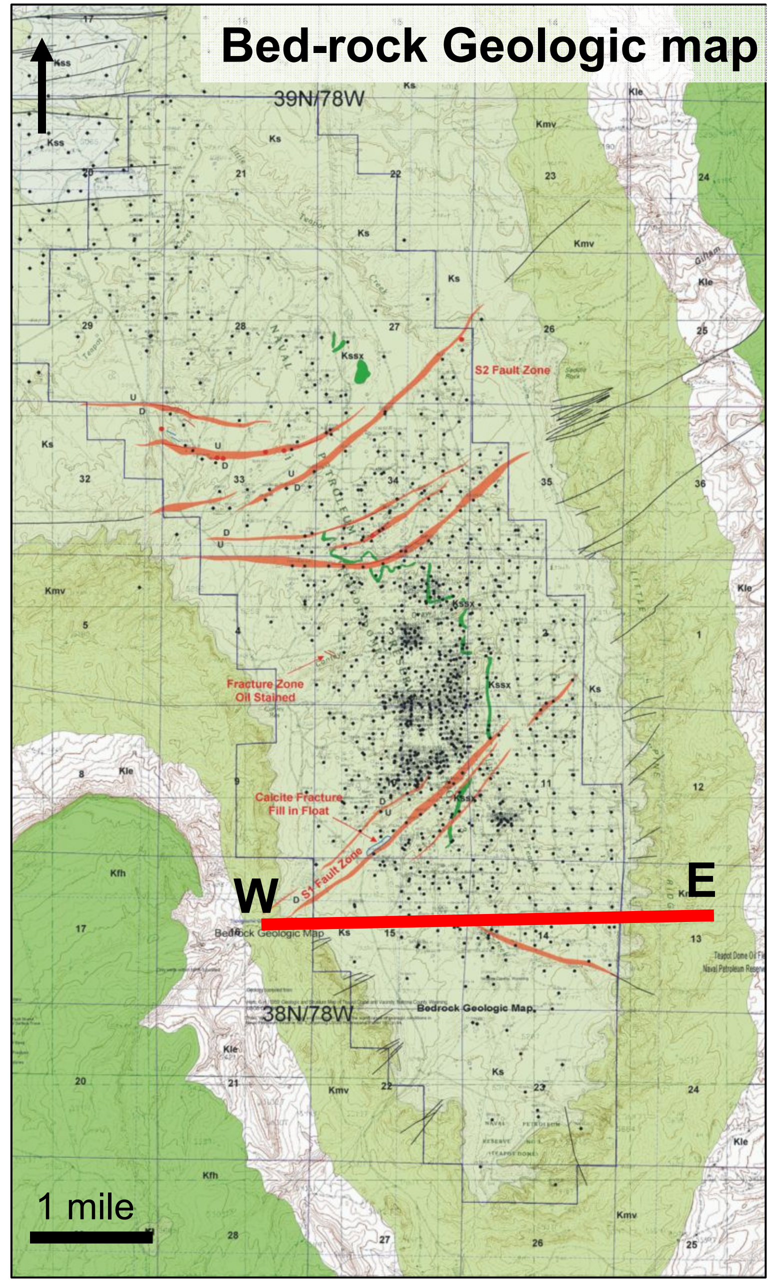
SW Powder River Basin - Central Rocky Mountains

Teapot Dome - Geology

- Basement-cored anticline
- West verging fault-propagation fold



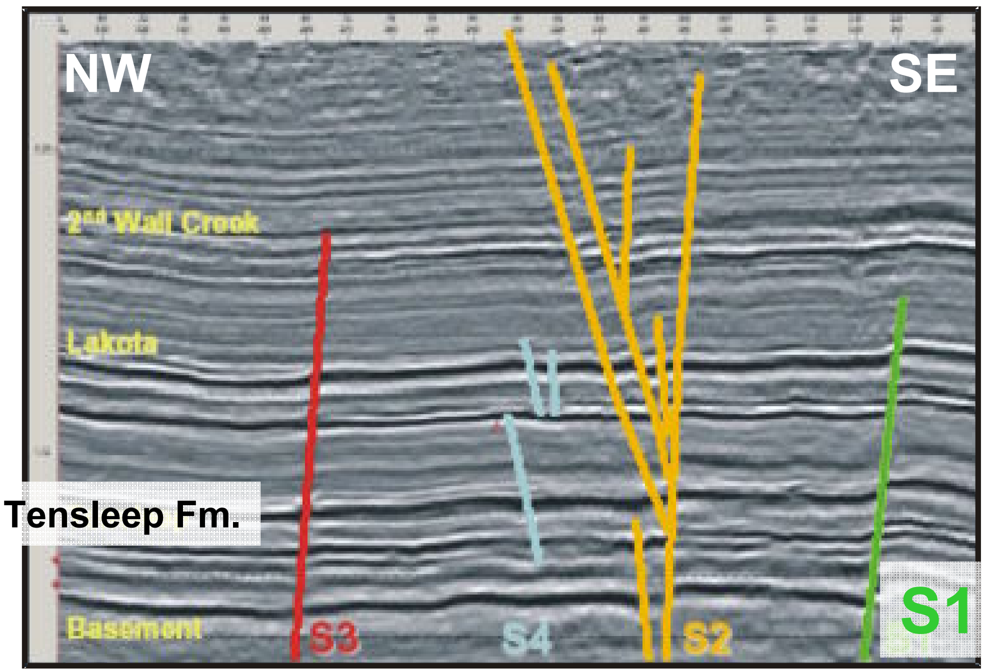
McCutcheon (2003)



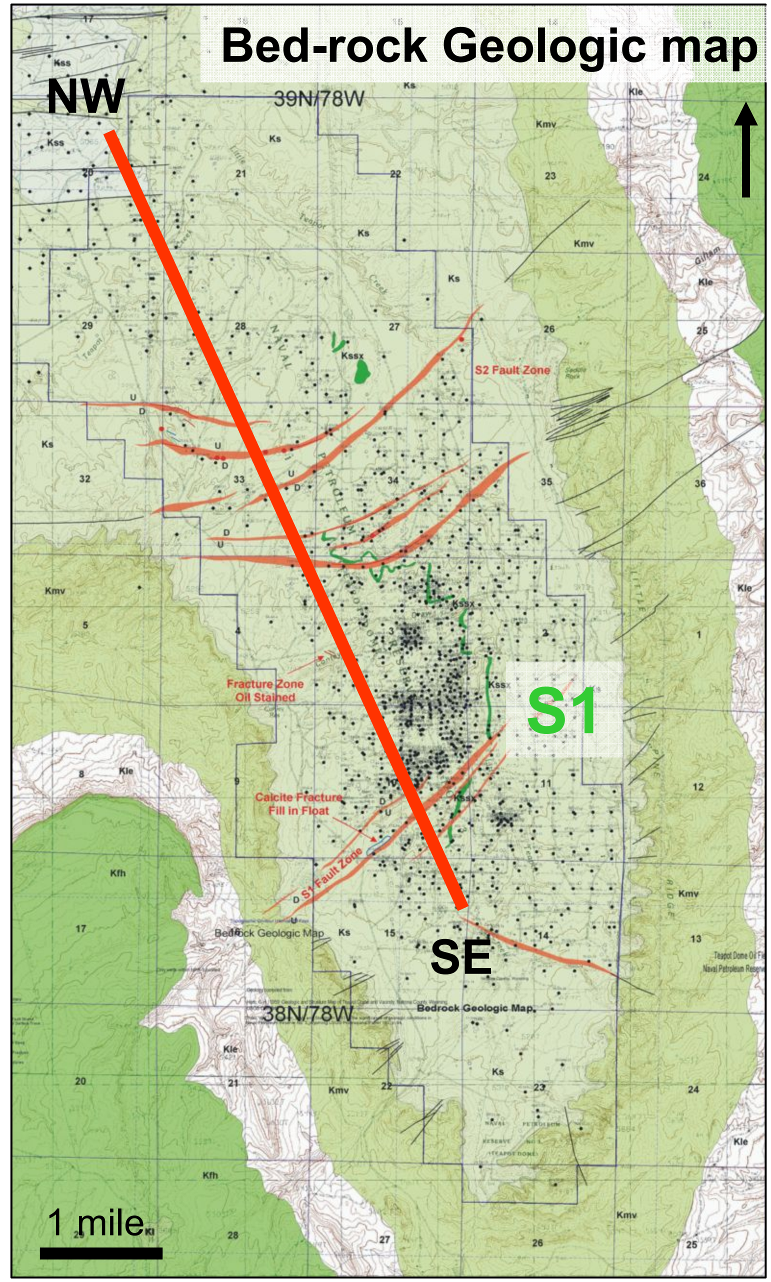
(courtesy J. Friedmann)

Teapot Dome - Geology

- Reservoirs compartmentalized by oblique strike-slip to normal faults

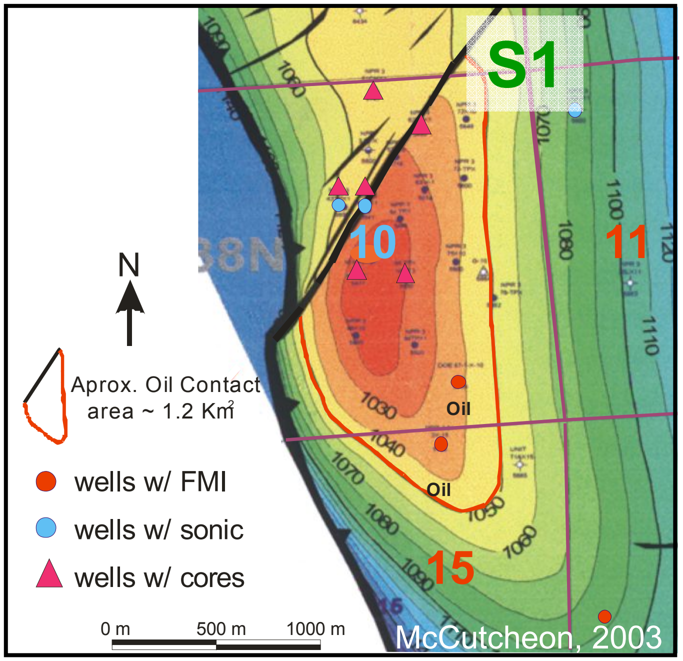


(Friedmann *et al.*, 2004)



Teapot Dome - Geology

Trap



Time structure map Tensleep Fm.

Structural crest → ~ 5320' (1620 m)

3-way closure bounded by S1 fault

Oil-contact area ~ 1.2 km^2

Reservoir

Tensleep Formation → B - Sand

Interdune deposits (sandstones, evaporites, etc.)

- Average Porosity 10 % (5 – 20 %)
- Average Permeability 30 mD (10 – 100 mD)

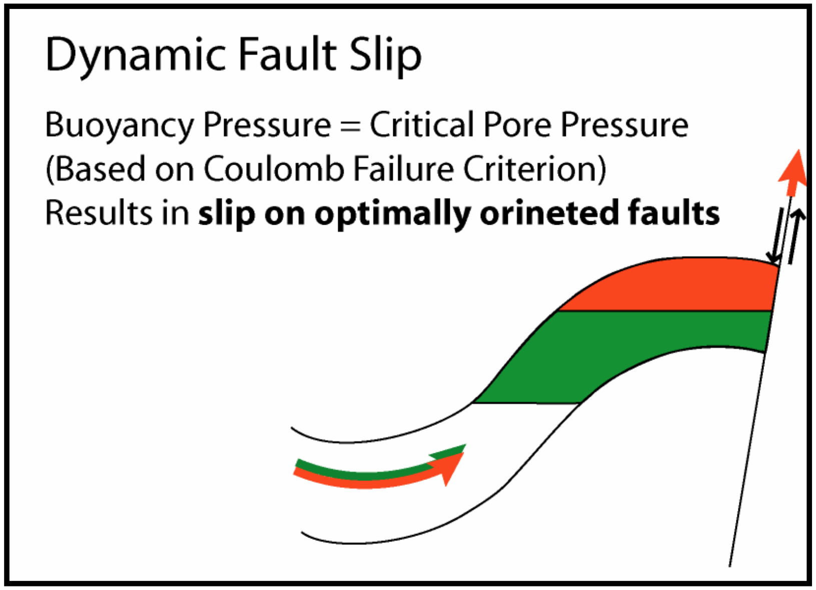
Top Seal

Paleosoil + Opeche Shale + Anhydrite (Minnekatha member)

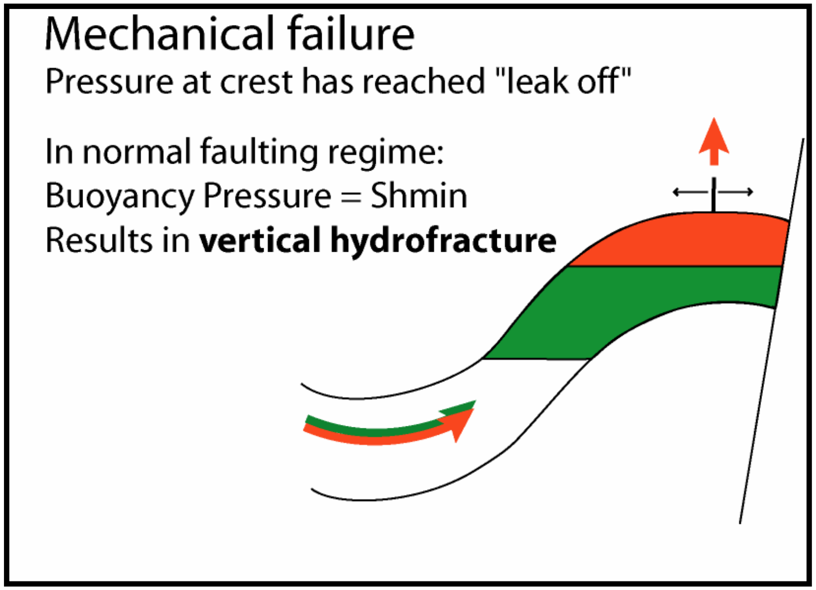
Motivation

- Will CO_2 Injection Affect Seal Capacity of Bounding S1 Fault & Integrity of Cap Rock?

Triggering slip on pre-existing fault



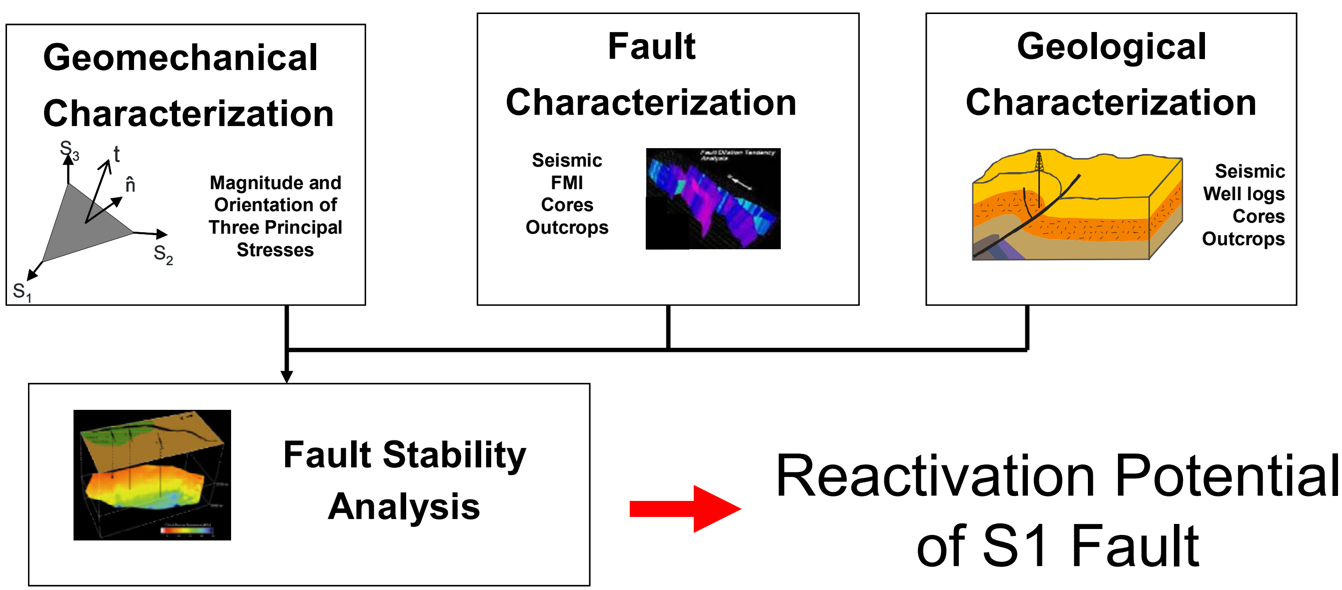
Hydraulic fracturing of cap rock



Objective

Reactivated faults provide conduits for fluid migration
(Wiprut & Zoback, 2001)

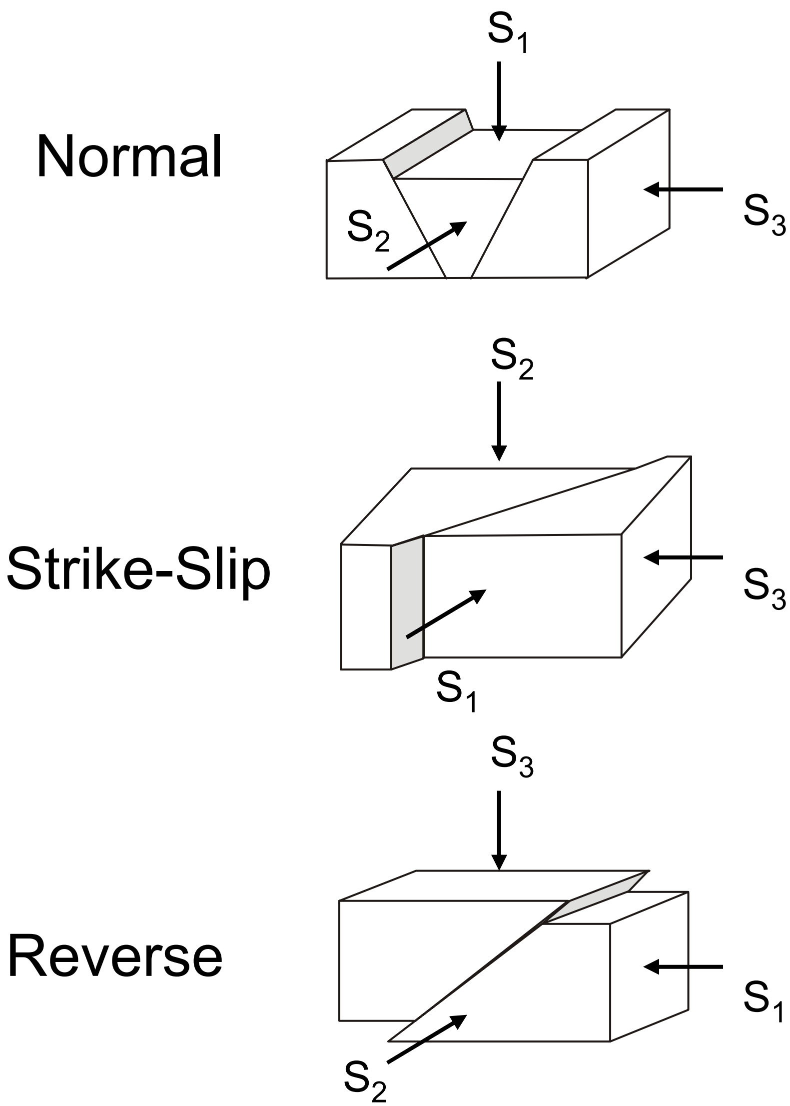
→Relationship between faults & present day stress field in order to understand & quantify risk of leakage



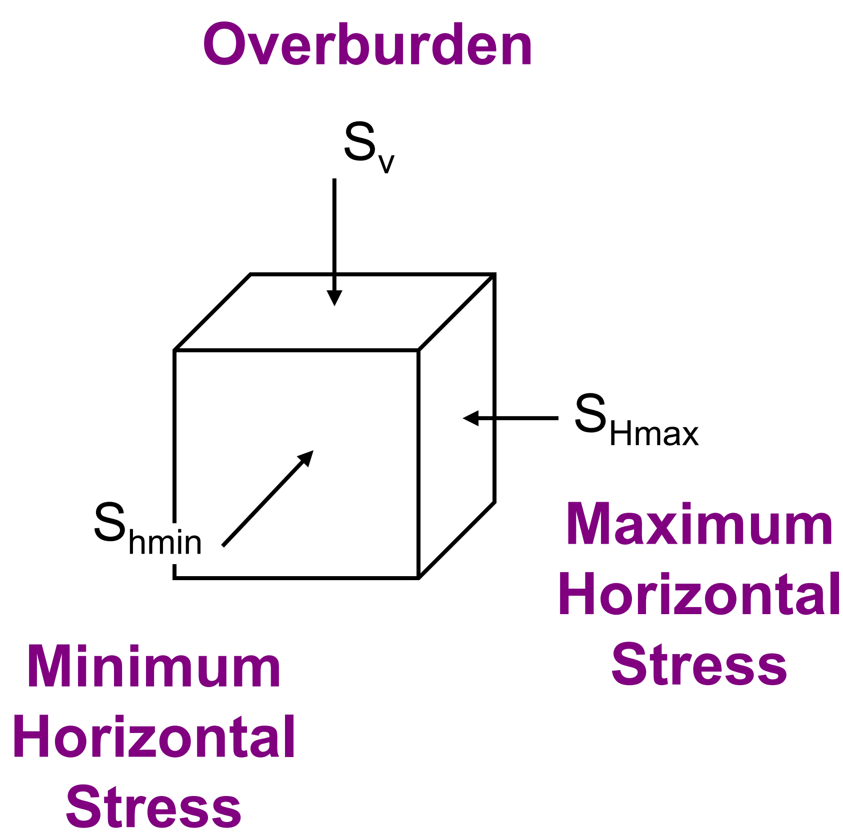
GCEP

Tectonic Regimes - Geomechanical Model

Anderson Classification

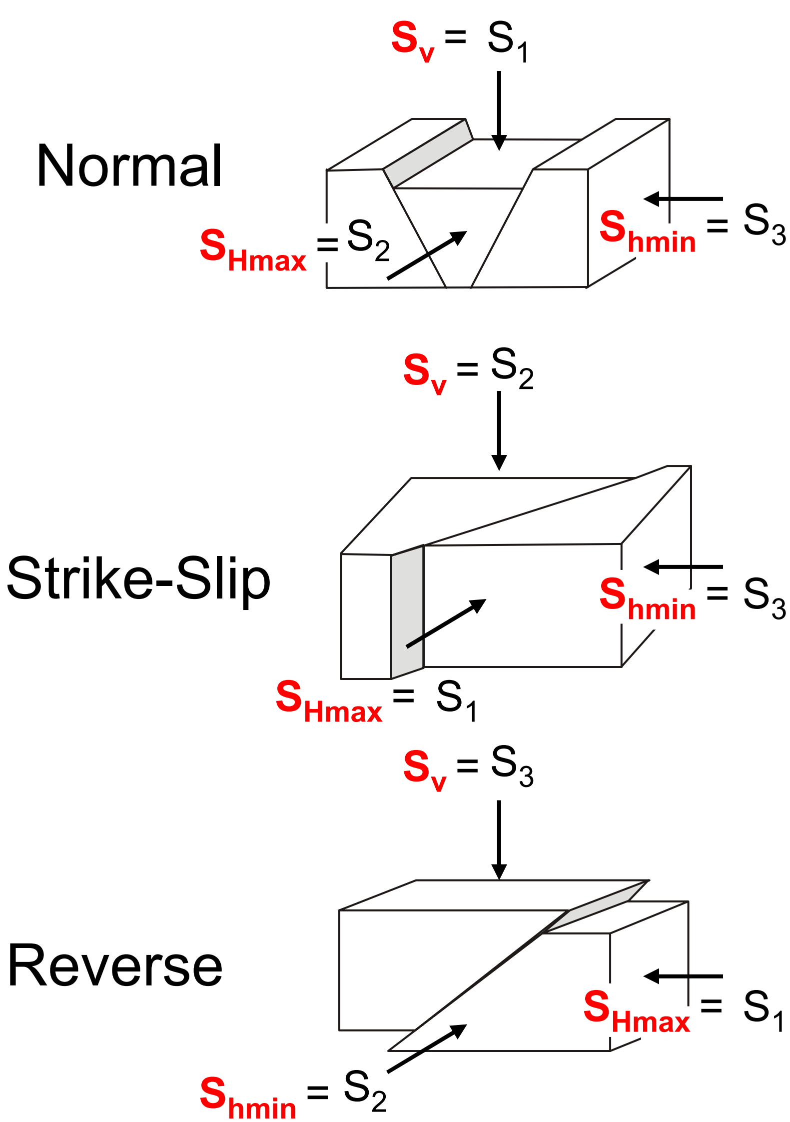


Stress Tensor

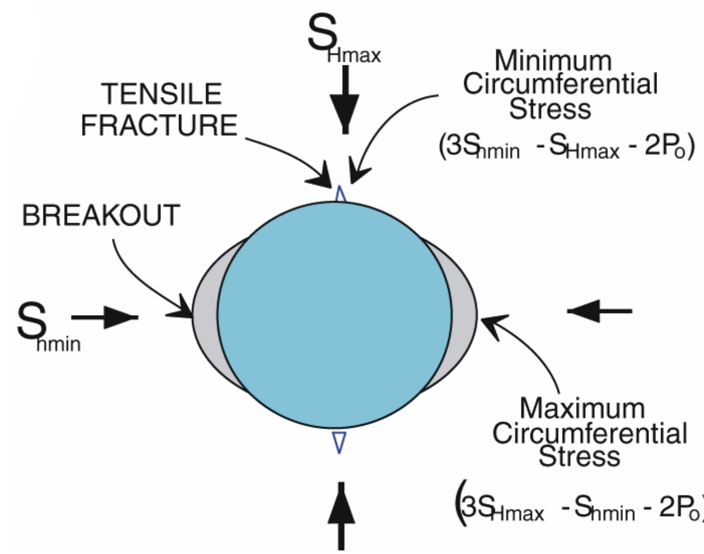


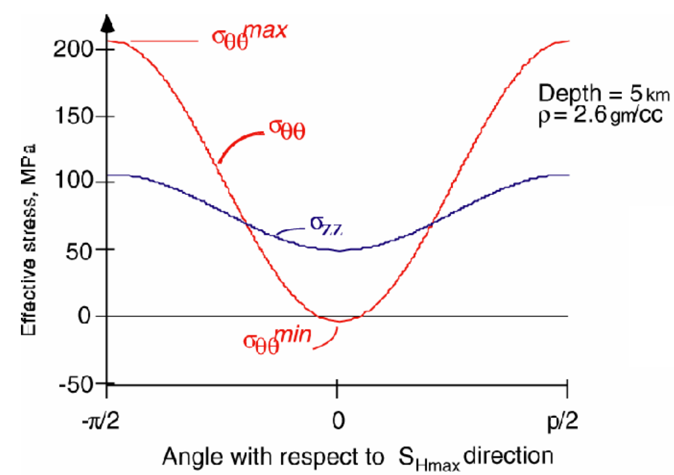
Tectonic Regimes - Geomechanical Model

Anderson Classification

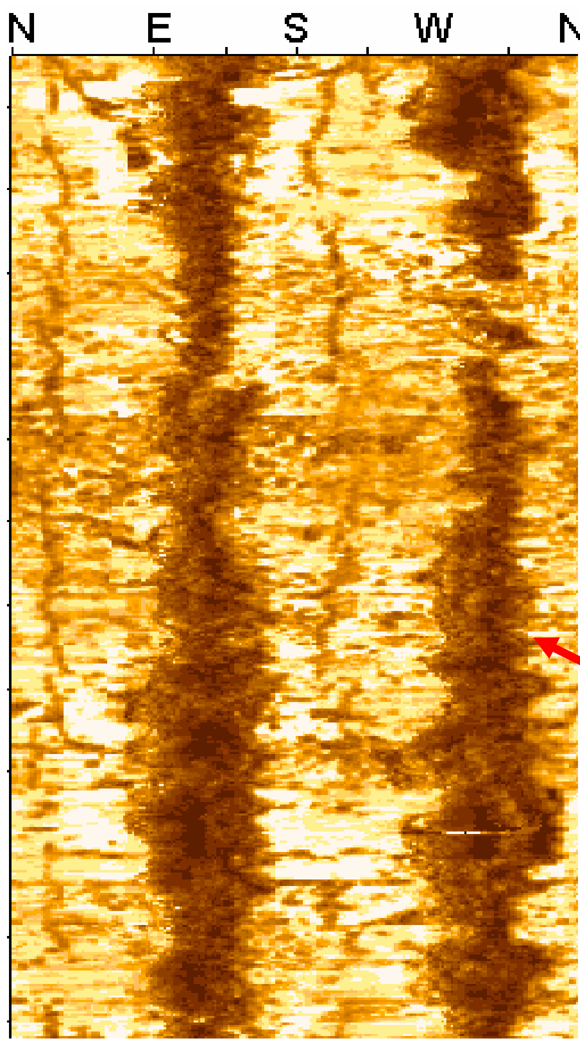


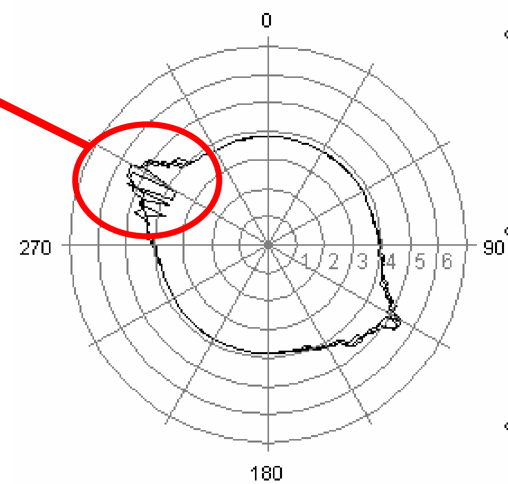
Stress Concentration Around a Vertical Well





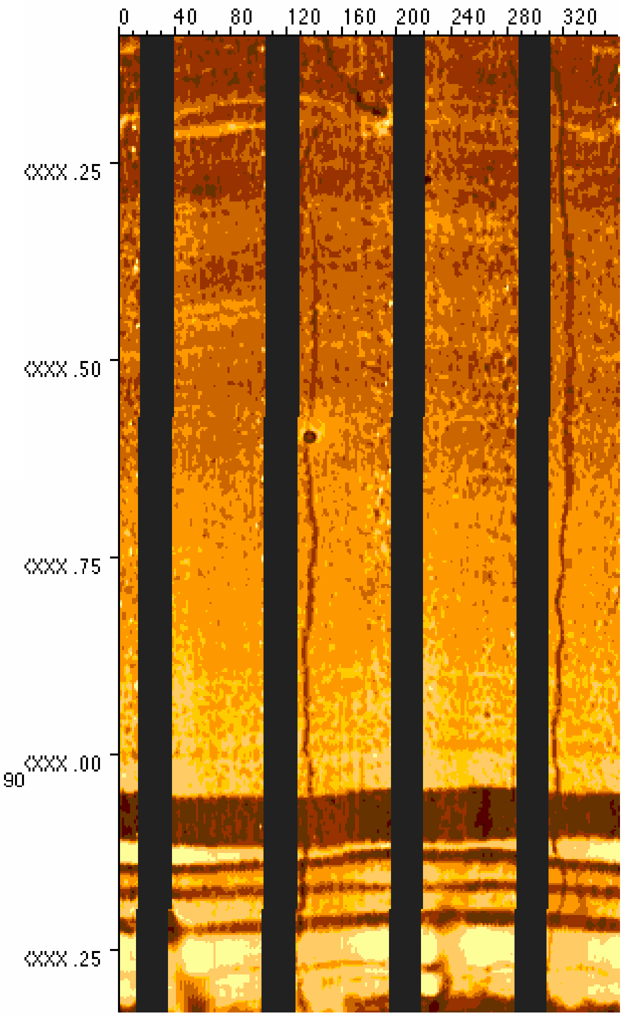
Wellbore Failure





Breakouts

Drilling Induced Tensile Fractures



Geomechanical Characterization - Stress Tensor

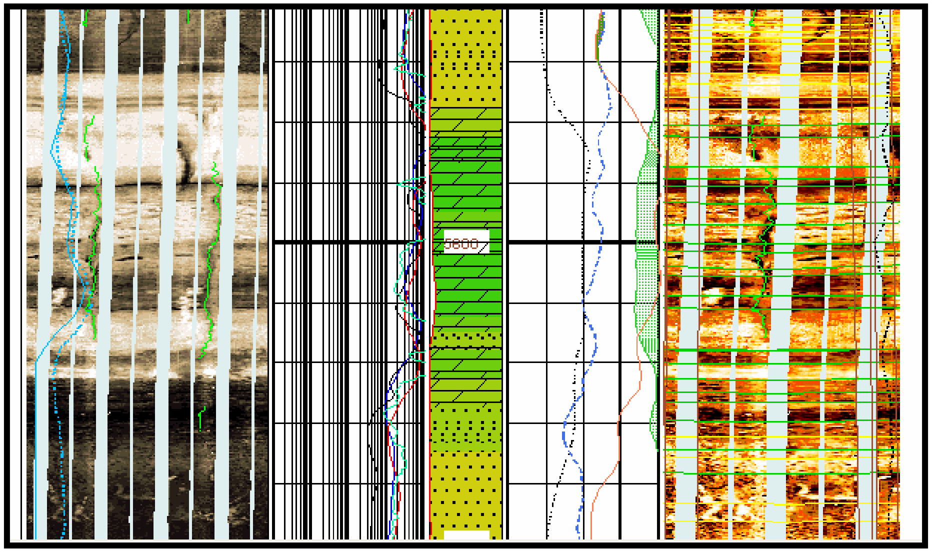
$$\mathbf{S} = \begin{bmatrix} S_{Hmax} & 0 & 0 \\ 0 & S_v & 0 \\ 0 & 0 & S_{hmin} \end{bmatrix}$$

- Stress orientation → Orientation of Tensile Fractures → Formation Microresistivity Imager (FMI) log
- Vertical stress → $S_v(z_0) = \int_0^{z_0} \rho g \, dz$ Density Logs
- Least principal stress → S_{hmin} magnitude
- Max. horizontal stress → S_{Hmax} magnitude

Stress Modeling

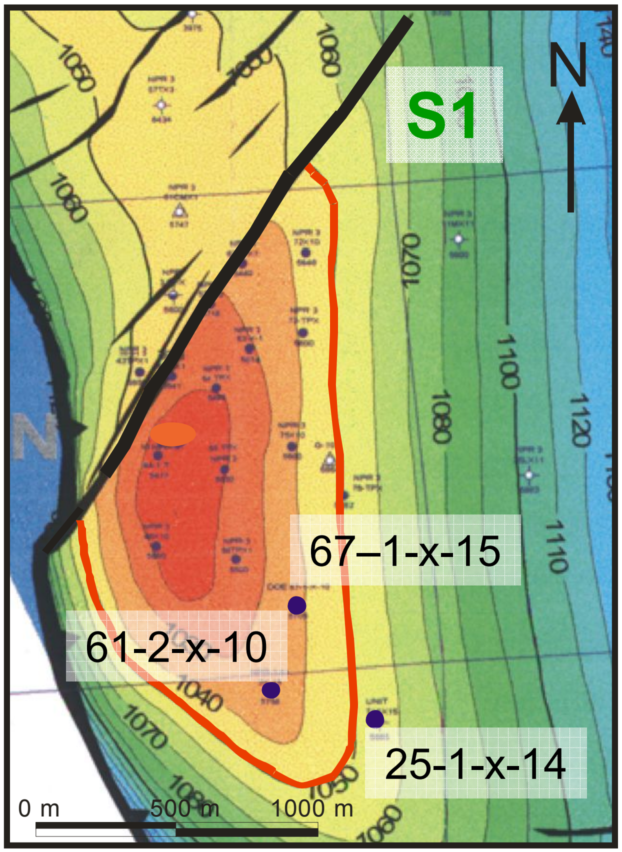
Stress and Failure of Inclined Boreholes (GMI•SFIB)

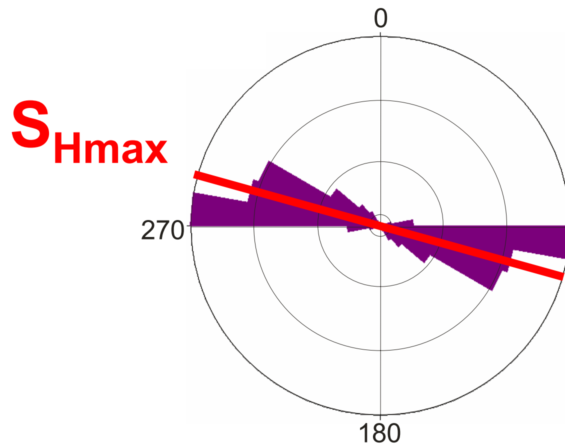
Geomechanical Characterization - Stress Tensor



- Pore pressure → Direct Measurements
- Rock Strength → Calculated from Logs
- Faults → Mapped from 3D Seismic

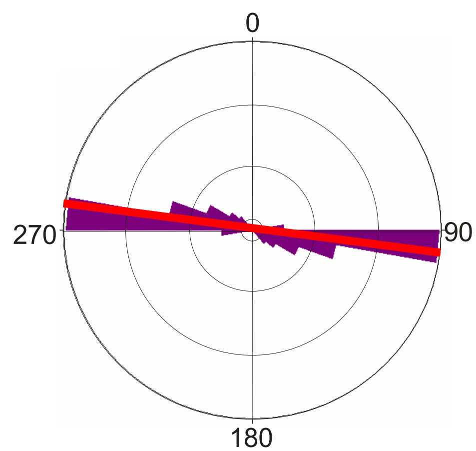
Stress Orientation from FMI logs - Tensile Fractures



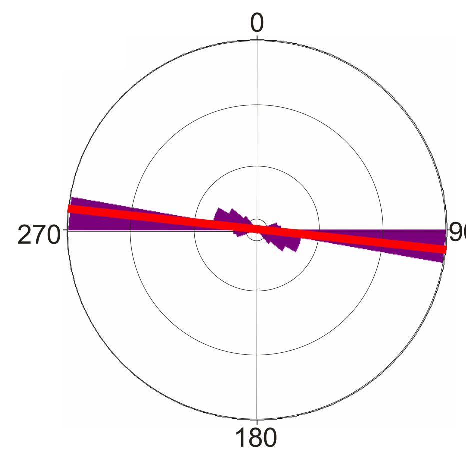


Well 67-1-X-10

(Milliken & Koespel, 2002)

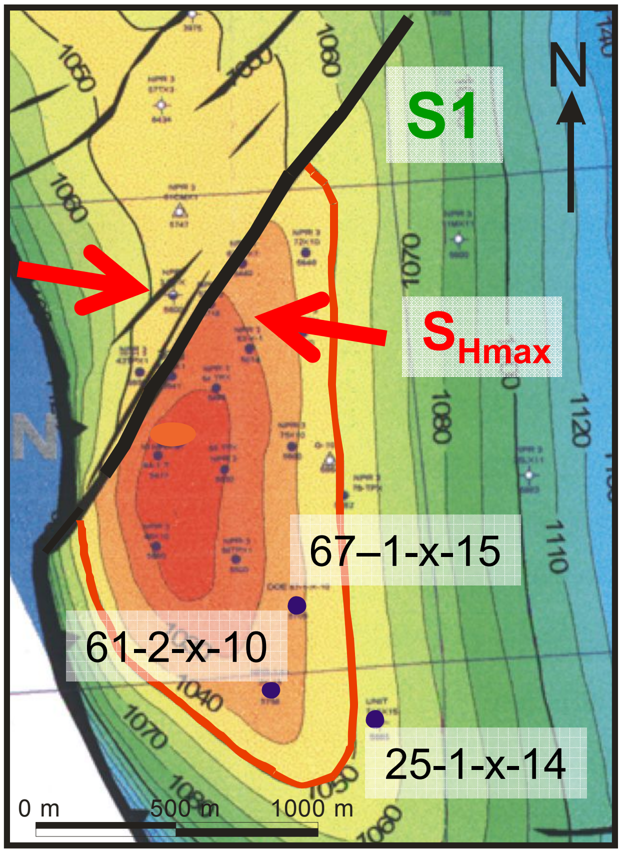


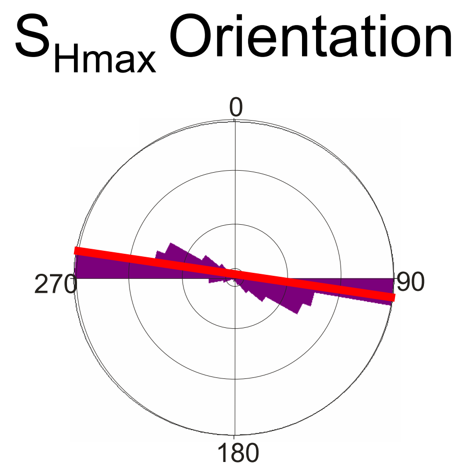
Well 61-2-X-15



Well 25-1-X-14

Stress Orientation from FMI logs - Tensile Fractures

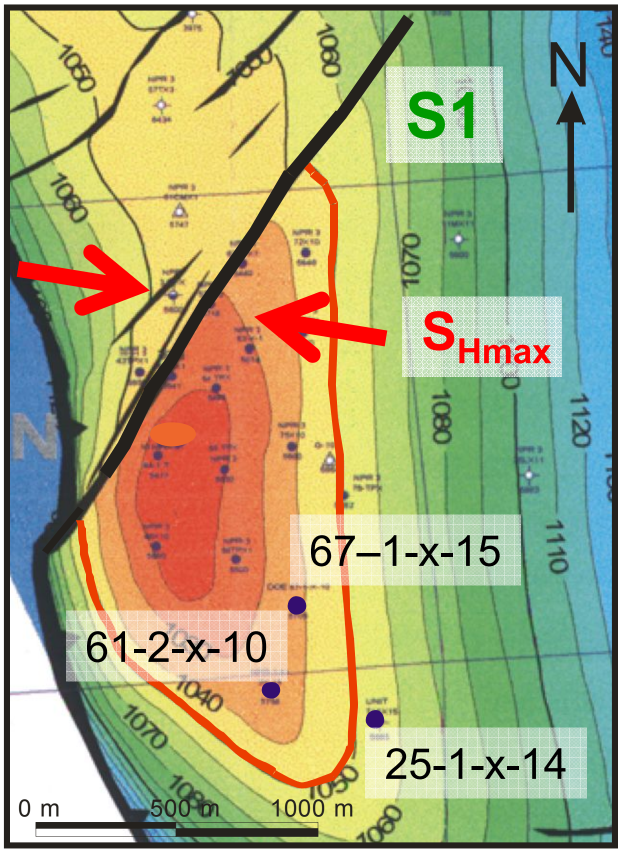




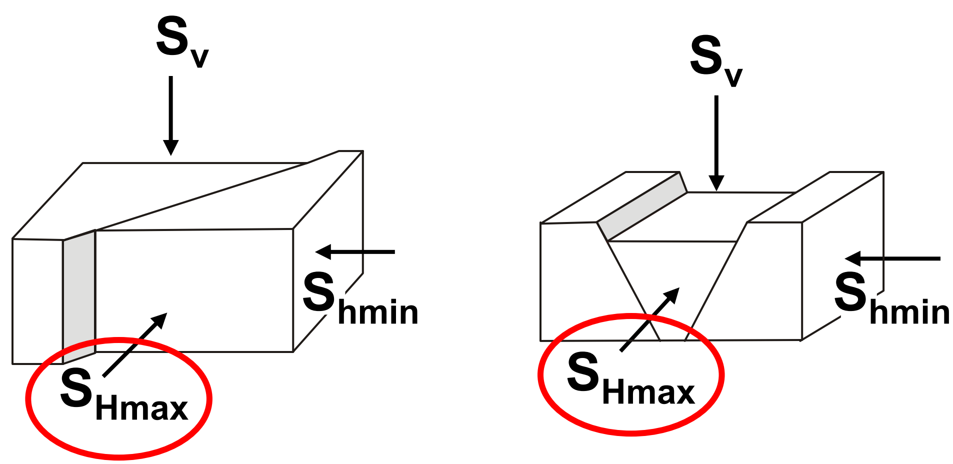
$Az = 95^{\circ} \pm 10^{\circ}$

- Stress orientation very consistent in analyzed wells
- 276 # of observations
- Range of depths: 400 – 1800 mts

Present-Day Stress & S1 Fault

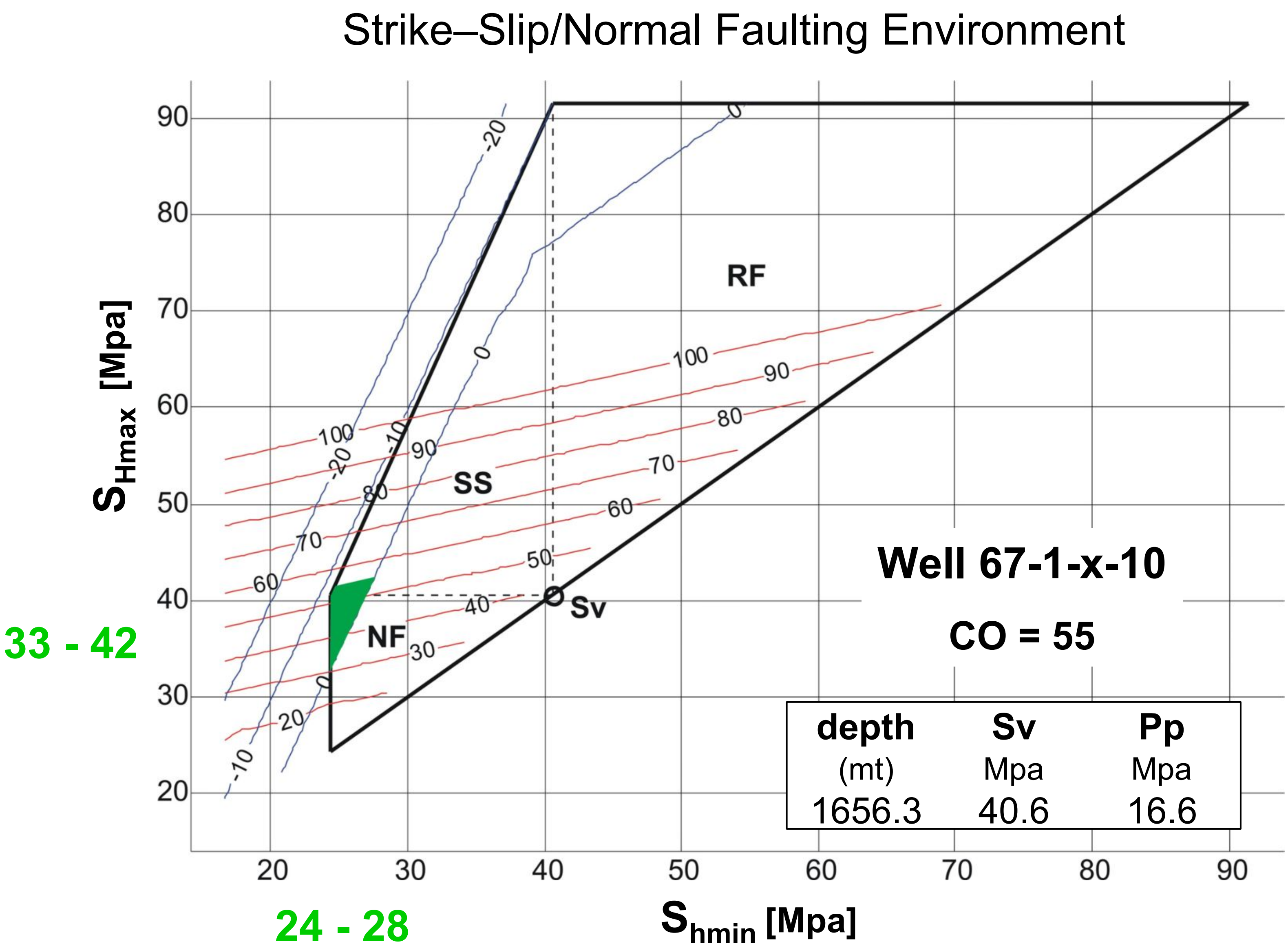


- Presence of Tensile Fractures
- No Breakouts Observed
- Seismic Observations



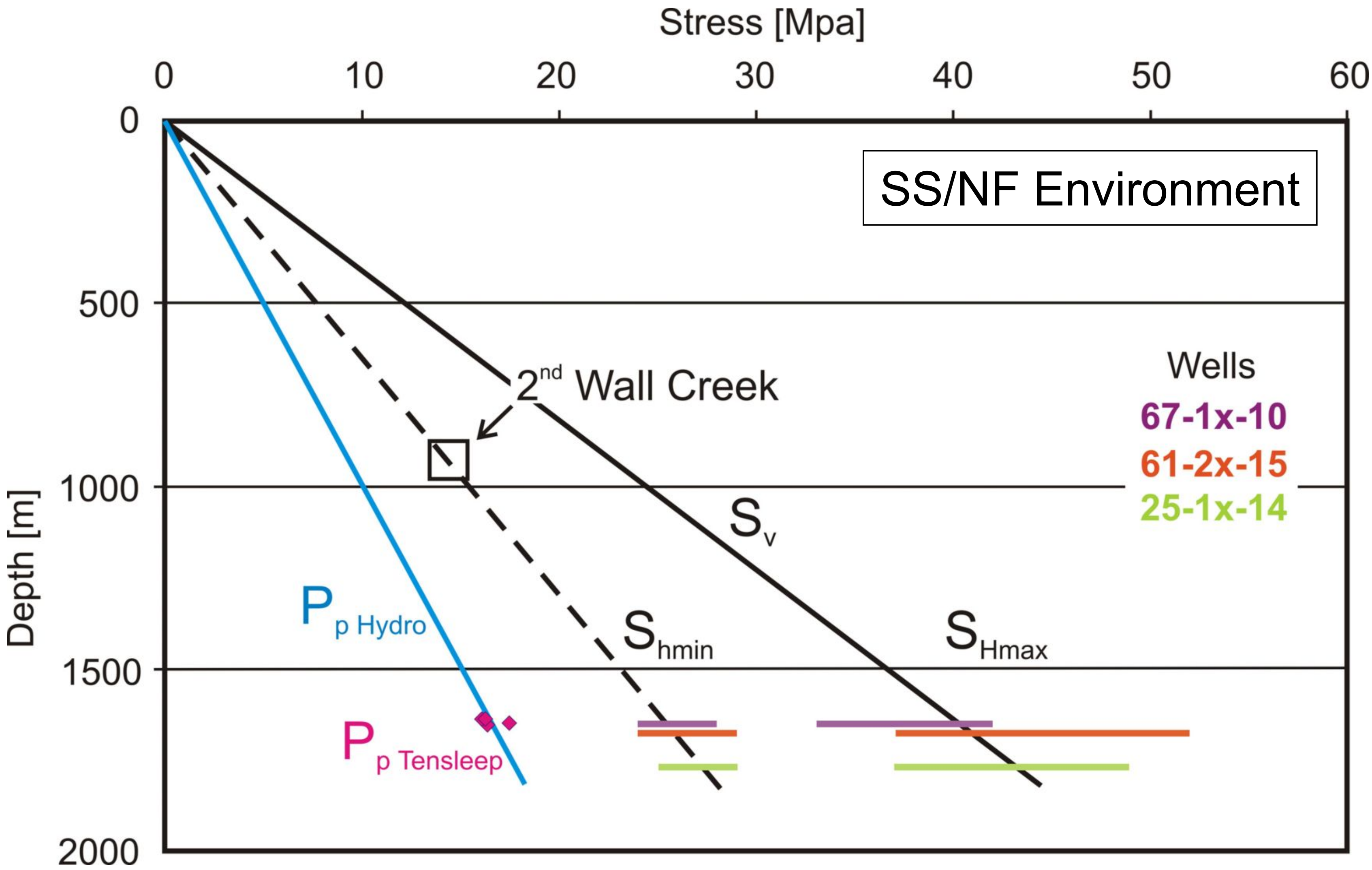
Not Favorable Oriented
→ SS/NF

S_{Hmax} & S_{hmin} Magnitudes



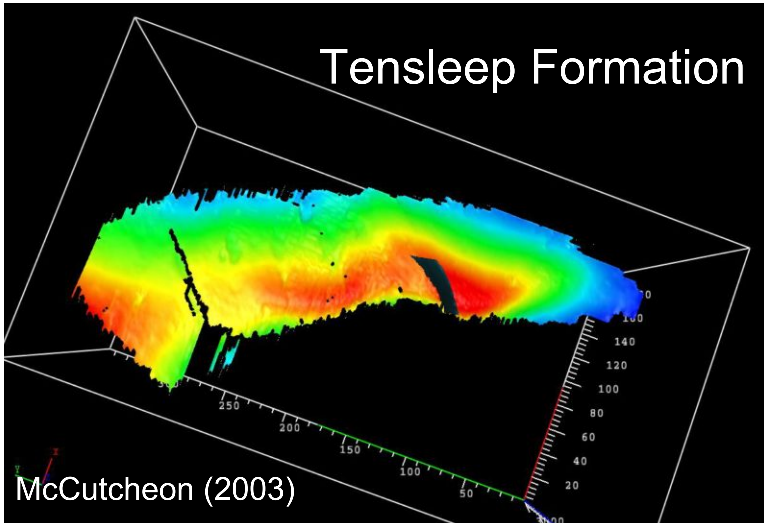
depth	Sv	Pp
(mt)	Mpa	Mpa
1656.3	40.6	16.6

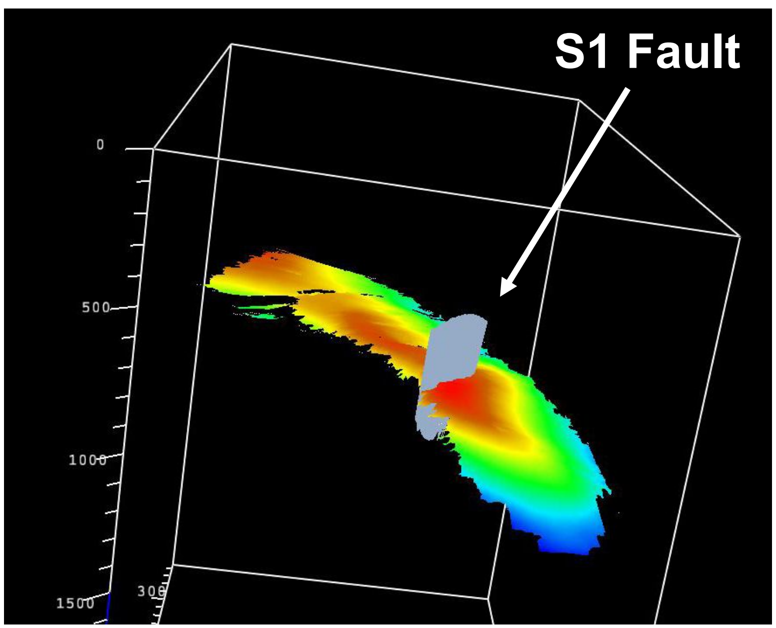
Stress Summary



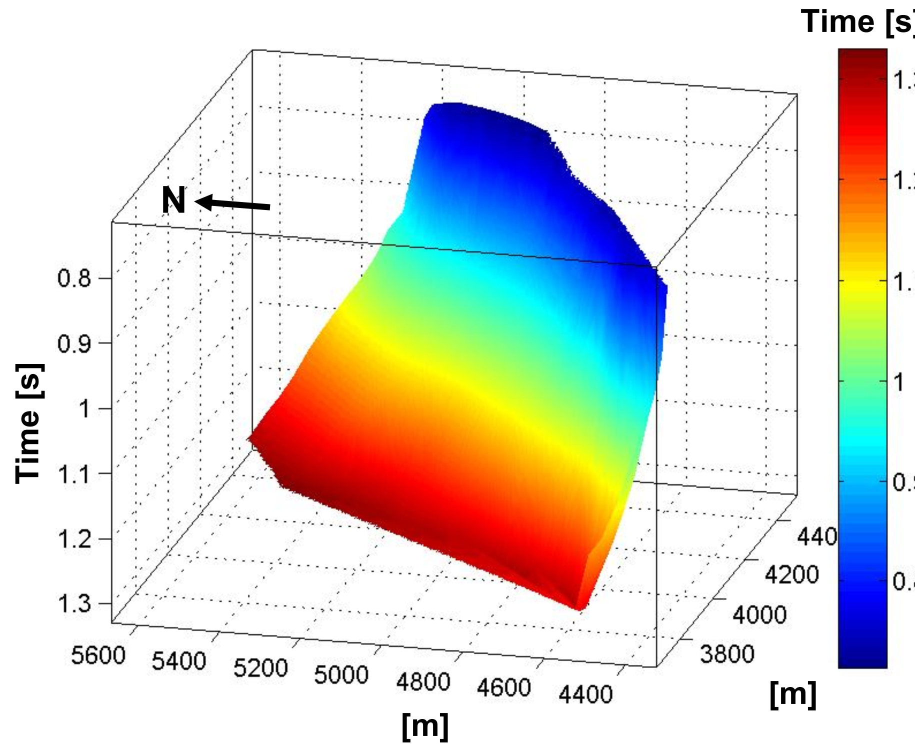
GCEP

Fault Characterization



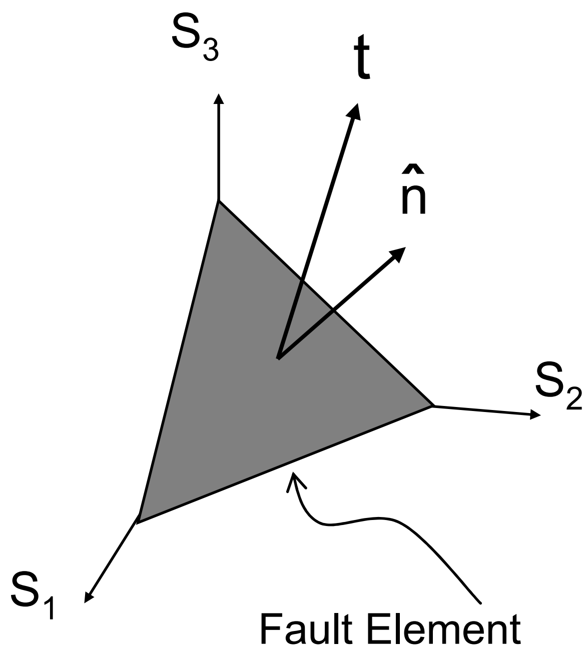


Exported S1 Fault Surface



TD conversion → Dip Moveout (DMO) velocities

Calculating the Fault Slip Potential Using Coulomb Criterion



$$S = \begin{bmatrix} S_{Hmax} & 0 & 0 \\ 0 & S_v & 0 \\ 0 & 0 & S_{hmin} \end{bmatrix}$$

$$t = S\,\hat{n}$$

$$S_n = \hat{n} \cdot t$$

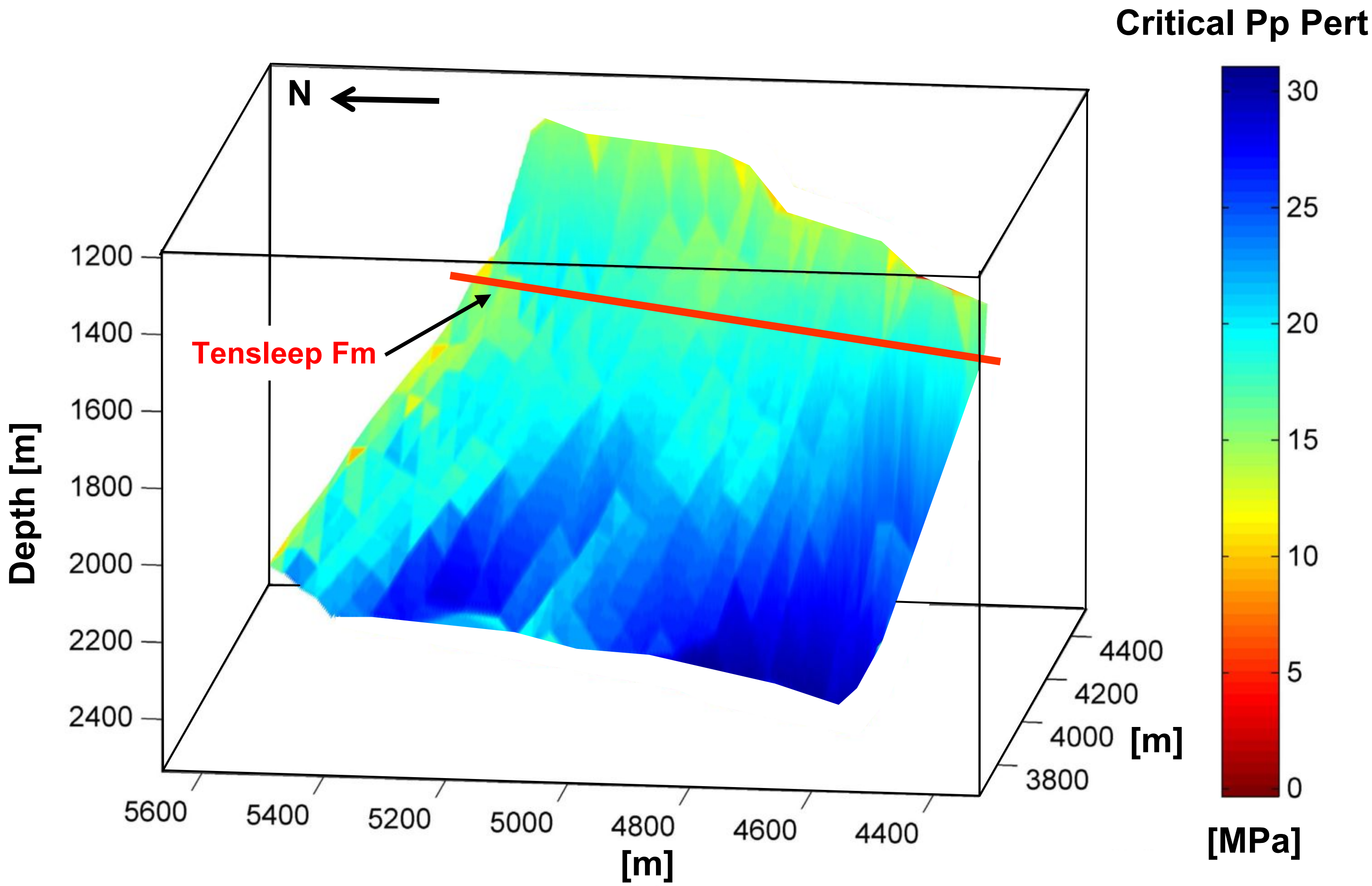
$$\tau^2 = t^2 - S_n^2$$

$\tau = \mu\,(S_n - P_p)$ → **Coulomb Criteria**

$P_{pc} = S_n - \tau/\mu$ → critical Pp

$P_{pc} - P_{ref}$ = Critical Pressure Perturbation

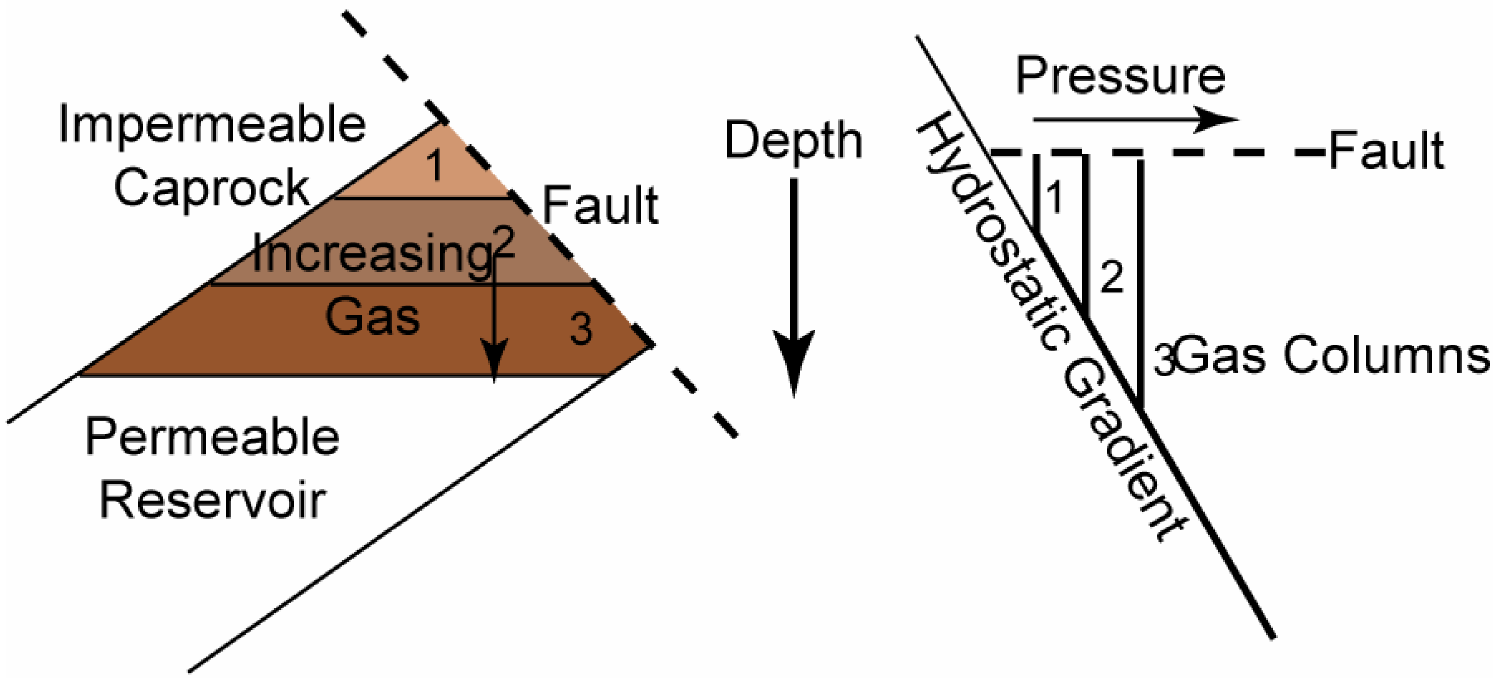
Critical Pressure Perturbation on S1 Fault



Excess Pore Pressure due to Gas Buoyancy

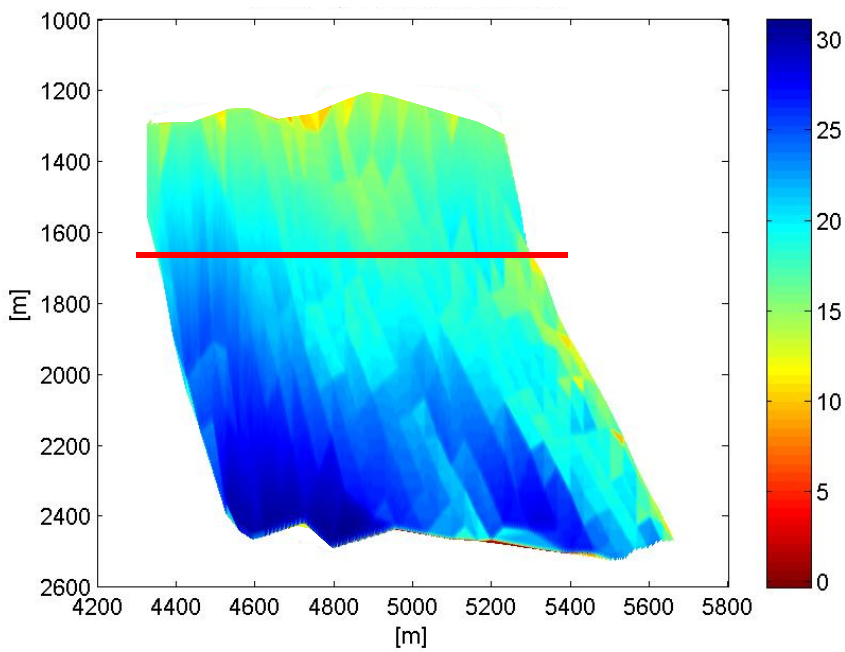
Schematic Geologic Cross-Section

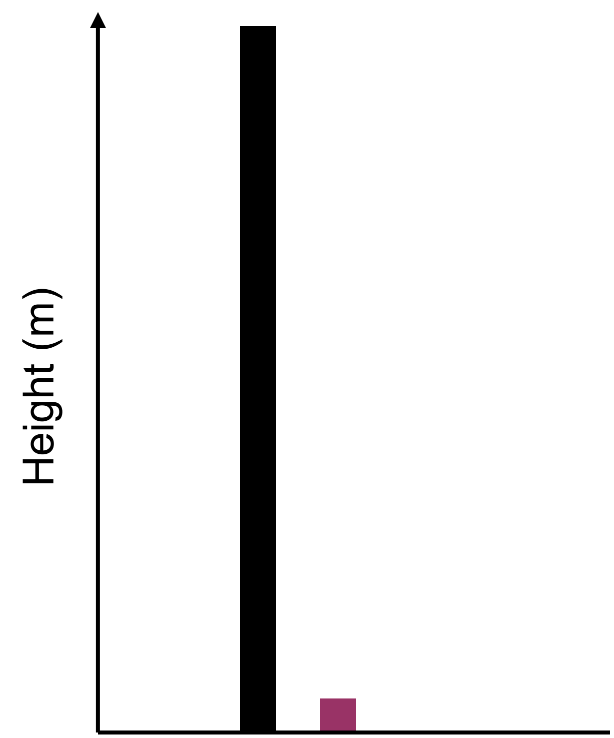
Pore Pressure Profile



Will the S1 Fault Reactivate?

This corresponds to CO_2 column height of ~2500 m (den = 700 kg/m³)





At Tensleep depth → it would require ~16 MPa of excess pressure to cause fault to slip

The average structural thickness of the Tensleep Fm. is ~ 100m

Future Work

- Refine Stress Model
  - Improve rock strength
  - LOT → Tensleep (mag S_{hmin})
  - LOT → Cap-Rock

Avoid hydrofracturing Cap-Rock

- Refine Structural Mapping
  - Vertical Extent of S1 Fault
  - Other faults? → sub-seismic

- Improve TD Conversion

Acknowledgments

- GCEP

- Brian Black, Tom Anderson & Mark Milliken (RMOTC)

- Tapan Mukerji & Kyle Spikes (Stanford University)

- Tim McCutcheon